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(19)

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(54) SYSTEM FOR THE DETERMINATION OF A RADIATION SCATTERING PROPERTY OF A FLUID

(71) We, EXOTECH INCORPORATED, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 1200 Quince Orchard Boulevard, Gaithersburg, Maryland, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention pertains to a system for the determination of a radiation scattering property of a fluid.

In numerous applications it is desirable to measure the scattering of radiation passing through a fluid. By way of illustration, from such measurements it is possible to determine properties of the scattering particles such as concentration and size distribution. Thus, for example, as a result of such measurements dust concentration in mines and industrial atmospheres can be monitored, particle concentrations in gases and liquids can be determined, the pollutant particle concentration in gases from smokestacks can be measured, and turbidity in liquids can be determined.

Numerous systems, exist for measuring the scattering or deflection of radiation passing through a fluid. but in general such existing systems suffer from shortcomings. For example, such devices suffer from increased error as particles collect on optical surfaces in the radiation transmission paths. Fluctuations in the radiation source or in the radiation detector responsivity are interpreted as variations in the scattering and coefficient of the fluid and so result in error. Any factors unrelated to the scattering coefficient but affecting the optical transmission through the fluid are interpreted as changes in the scattering coefficient. Thus, since such devices in general rely upon measurement of the cross radiation reaching the radiation detector, any cause of fluctuation in that radiation becomes a part of the system output signal, although numerous causes of fluctuation are not related to the properties of the medium which it is desired to measure.

Apparatus for determining the radiation scattering coefficient S_θ within a fluid for a scattering angle θ comprises, according to this invention, a fluid zone adapted to contain a fluid; first radiation means including a first radiation detector and a first radiation source for emitting radiation through the fluid zone in a first straight-line path to the first radiator detector; second radiation means including a second radiation detector and a second radiation source for emitting radiation through the fluid zone in a second straight line path to the second radiation detector, the second straight-line path intersecting the first straight-line path at an angle θ; and circuit means connected to the first and second radiation detectors for generating the scattering coefficient S_θ for the scattering angle θ from the outputs of the first and second radiation detectors.

In another aspect, the invention provides apparatus for determining the radiation scattering coefficient S_θ within a fluid for a scattering angle θ comprising a fluid zone to contain a fluid; first radiation means including a first radiation detector and a first radiation source for emitting radiation through the fluid zone in a first straight-line path to the first radiation detector; second radiation means including a second radia-

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tion detector and a second radiation source for emitting radiation through the fluid zone in a second straight line path to the second radiation detector, the second straight-line path intersecting the first straight-line path at an angle θ; excitation means connected to the first and second radiation sources; means for obtaining a first signal in accordance with the output A_{11} of the first detector due to radiation from the first radiation source; means for obtaining a second signal in accordance with the output A_{12} of the first detector due to radiation from the second radiation source; means for obtaining a third signal in accordance with the output A_{21} from the second detector due to radiation from the first radiation source; means for obtaining a fourth signal in accordance with the output A_{22} from the second detector due to radiation from the second radiation source; and means for generating from the four signals a signal representing the scattering coefficient S_θ for the scattering angle θ. Preferably, the generating means are arranged to combine together the first to fourth signals according to the equation

$$S_\theta = \left[(A_{21}\ A_{12}) / (A_{11}\ A_{22})\right]^{1/2}$$

The invention will be more readily understood by way of example from the following description of a system in accordance therewith for determining the radiation scattering coefficient of a fluid medium, reference being made to the accompanying drawings, in which:—

Figure 1 is a block diagram representation of the system; and

Figure 2 is a block diagram of a circuitry suitable for use as processing equipment in the system of Figure 1.

As depicted in Figure 1, radiation source 10 and radiation source 12 are connected via lines 11 and 13, respectively, to drive source 14 to be envisaged. Drive source 14 is a source of suitable electrical potential which alternately energizes radiation source 10 and radiation source 12. For example, drive source 14 can have an energization cycle providing application of excitation for a brief period to radiation source 10, application of excitation for a brief period to radiation source 12, and a brief period during which no excitation is provided to permit compensation for ambient light. Radiation sources 10 and 12 might be any suitable sources of light such as tungsten lamps, light emitting diodes, gas discharge tubes and lasers.

Instead of alternately pulsing radiation sources 10 and 12, each source could be continuously energized and modulated by a unique signal, with filtering in the outputs of detectors 18 and 22 to separate the received signals into its two constituents.

Radiation from source 10 traverses straight-line path 16 to radiation detector 18. Likewise radiation from source 12 traverses straight-line path 20 to radiation detector 22. Radiation paths 16 and 20 intersect in zone 24 at an angle θ which is the scattering angle of interest. Angle θ can be any scattering angle of interest and might range from 0° to 180° in either direction from path 16. Zone 24 is the area in which paths 16 and 20 overlap and in which the fluid medium is located. Particles suspended within the fluid medium in zone 24 cause deflection or scattering of the radiation from sources 10 and 12 so that some of the radiation from source 10 is received by radiation detector 22 and some of the radiation from source 12 is received by radiation detector 18. Zone 24 can be defined by a container through which paths 16 and 20 pass, or a container can house not only zone 24 but also radiation sources 10 and 12 and radiation detectors 18 and 22. The output of radiation detector 18 is applied to amplifier 26, while the output of radiation detector 22 is applied to amplifier 28. Line 11, which applies excitation output of drive source 14 to radiation source 10, is also connected to gain control circuit 30, the output of which is utilized to control the gain within amplifier 26. In like manner, line 13, which applies the excitation output of drive source 14 to radiation source 12, is connected to gain control circuit 32, the output of which is utilized to control the gain within amplifier 28. The outputs of amplifiers 26 and 28 are connected via lines 27 and 29, respectively, to processing equipment 34 which provides the scattering coefficient S_θ on its output line 36.

When radiation source 10 is energized, radiation from source 10 is received by both radiation detector 18 and radiation detector 22. If as designated in the drawing, A_1 is the output of radiation detector 18 so that A_{11} is the output of radiation detector 18 when radiation source 10 is energized and A_{12} is the output of radiation detector 18 when radiation source 12 is energized, T_1 is the radiation transmission coefficient from radiation source 10 to zone 24, T_2 is the radiation transmission coefficient from

zone 24 to radiation detector 18, I_1 is the radiation output from source 10, and R_1 is the radiation responsivity of detector 18, then the output of radiator detector 18 when radiation source 10 is energized is given by $A_{11}=I_1\ T_1\ T_2\ R_1$. The radiation transmittance coefficient of an element is a number between 0 and 1 defining the portion of incident radiation which is transmitted through the element. Likewise, if A_2 is the output of radiation detector 22 so that A_{22} is the output of radiation detector 22 when radiation source 12 is energized and A_{21} is the output of radiation detector 22 when radiation source 10 is energized, T_4 is the radiation transmission coefficient from zone 24 to detector 22, R_2 is the radiation responsivity of detector 24, and S_θ is the scattering coefficient within zone 24 over the angle θ, then when radiation source 10 is energized, the output of radiation detector 22 is given by $A_{21}=I_1\ T_1\ T_4\ R_2\ S_\theta$. If T_3 is the radiation transmission coefficient from source 12 to zone 24 and I_2 is the radiation output from source 12, then when radiation source 12 is energized, and its radiation is detected by both detector 18 and detector 22, the output of radiation detector 18 is $A_{12}=I_2\ T_3\ T_2\ R_1\ S_\theta$, while the output of detector 22 is $A_{22}=I_2\ T_3\ T_4\ R_2$. By combining these detector outputs, an expression for the scattering coefficient S_θ within zone 24 is obtained:

$$\frac{A_{21}A_{12}}{A_{11}\,A_{22}} = \frac{(I_1\,T_1\,T_4\,R_2\,S_\Theta)\;(I_2\,T_3\,T_2\,R_1\,S_\Theta)}{(I_1\,T_1\,T_2\,R_1)\;(I_2\,T_3\,T_4\,R_2)} = S_\Theta^{\,2}.$$

Therefore

$$S_\Theta = \left[(A_{21}\ A_{12})\ /\ (A_{11}\ A_{22})\right]^{1/2}$$

This scattering coefficient is calculated electronically by process equipment 34. The scattering coefficient of a volume containing small particles is a number between 0 and 1 defining that portion of the incident radiation which is scattered by the particles within the volume. In practice, to determine properties of the fluid zone 24, the value of S_θ can be determined for several values of angle θ, and the maximum S_θ and corresponding angle θ used in determining the properties of the fluid. Since the signal A_{11} resulting from radiation travelling directly from radiation source 10 to radiation detector 18 is of a considerably greater strength than is the signal A_{12} resulting from radiation received by detector 18 from source 12, during the time that radiation source 10 is energized by drive source 14, gain control circuit 30 reduces the gain of amplifier 26. Likewise, since the signal A_{22} is of a considerably greater strength than is the signal A_{21}, during the time that radiation source 12 is energized by drive source 10, gain control circuit 32 reduces the gain of amplifier 28. Consequently, regardless of which radiation source is energized, the outputs of amplifiers 26 and 28 are of the same order of magnitude. These gain control factors can be considered as a constant in the S_θ equation and thus can be automatically compensated in processing equipment 34.

Processing equipment 34 includes means for generating the scattering coefficient S_θ from the outputs of amplifiers 26 and 28 as radiation sources 10 and 12 are alternately energized. Thus, processing equipment 34 include circuitry for obtaining and storing signals according to the outputs of amplifiers 26 and 28 during the energization cycle of radiation sources 10 and 12. Processing equipment 34 can include means in the form of electronic multipliers and dividers, for generating a signal representing the scattering coefficient S_θ by operating directly on the outputs of amplifiers 26 and 28. Alternatively the means for generating a signal representing S_θ can include suitable electronic switching and a single logarithmic circuit to determine the logarithms of the signals received from amplifiers 26 and 28 which can then be summed with appropriate signs, divided by two, and passed through an antilog circuit to provide the scattering coefficient S_θ. Figure 2 depicts such processing equipment. Output lines 27 and 29 from amplifiers 26 and 28, respectively, are connected respectively to fixed contacts 40a and 40b of single-pole-double-throw switch 40. The moving contact 40c of switch 40 is tied to the input of logarithmic circuit 42.

The output of logarithmic circuit 42 is connected to one contact of each single-pole-single-throw switch 44, 46, 48, and 50. The second contacts of the switches 44, 46, 48, and 50 are connected to the inputs of sample-and-hold circuits 52, 54, 56, and 58, respectively, which, for example, might each be a capacitive voltage sampling circuit, and which, with the switches 42, 44, 46, 48 and 50, constitute means for obtaining and storing signals in accordance with the outputs A_{11}, A_{21}, A_{22} and A_{12}. The

outputs of sample-and-hold circuits 52, 54, 56 and 58 are applied to means for combining the logarithm signals, in the form of summing circuits 60, 64; thus, the outputs of circuits 52 and 56 are applied to the two inputs of summing circuit 60, which has its output coupled through inverter 66 to one input of summing circuit 62. In a similar manner, the outputs of sample-and-hold circuits 54 and 58 are connected to the two inputs of summing circuit 64, the output of which is connected to the second input of summing circuit 62. The output of summing circuit 62 is connected to the input of dividing circuit 68, which divides the input voltage applied thereto by two. The output of dividing circuit 68 is tied to the input of anti-logarithmic circuit 70, the output of which is the processing equipment output line 36. If desired, the output of anti-logarithmic circuit 70 can also be connected to averaging circuit 72 to provide an indication of average value of S_θ.

Lines 11 and 13, which provide energizing potential for drive source 14 to radiation sources 10 and 12, respectively are also applied as inputs to controllers 74 which controls operation of switches 40, 44, 46, 48 and 50. When line 11 provides energizing potential to radiation source 10, controller 74 causes switch 40 to close contact 40c against contact 40a and causes switch 44 to close. The remaining switches 46, 48 and 50 are open. The logarithm of the A_{11} value is then stored in sample-and hold circuit 52. Controller 74 then causes switch 40 to close contact 40c against contact 40b and causes switch 44 to open and switch 46 to close, while switches 48 and 50 remain open. The logarithm of the A_{21} value is then stored in sample-and-hold circuit 54. When line 13 then provides energizing potential to radiation source 12, controller 74 causes switch 40 to close contact 40c against contact 40b and causes switch 48 to close while switches 44, 46, and 50 are open. The logarithm of the A_{22} value is then stored in sample-and-hold circuit 56. Controller 74 then causes switch 40 to close contact 40c against contact 40a and causes switch 48 to open and switch 50 to close, while switches 44 and 46 remain open. The logarithm of the A_{12} value is then stored in sample-and-hold circuit 58.

The output of summing circuit 60 is thus [log A_{11}+log A_{22}], while the output of summing circuit 64 is [log A_{21}+log A_{12}]. Consequently, the output of summing circuit 62 is

$$\left[(\log A_{21} + \log A_{12}) - (\log A_{11} + \log A_{22})\right]$$

and the output of dividing circuit 68 is one-half that value. Antilog circuit 70 converts this value into the value of S_θ which is applied to output line 36 and to averaging circuit 72 which provides a reading of the average S_θ value.

Averaging circuit 72 can be an integrator or a device such as a mercury microcoulometer which provides the time average value of the signal applied to it.

WHAT WE CLAIM IS:—

1. Apparatus for determining the radiation scattering coefficient S_θ within a fluid for the scattering angle θ comprising a fluid zone to contain a fluid; first radiation means including a first radiation detector and a first radiation source for emitting radiation through the fluid zone in a first straight-line path to the first radiation detector; second radiation means including a second radiation detector and a second radiation source for emitting radiation through the fluid zone in a second straight line path to the second radiation detector, the second straight-line path intersecting the first straight-line path at an angle θ; and circuit means connected to the first and second radiation detectors for generating the scattering coefficient S_θ for the scattering angle θ from the outputs of the first and second radiation detectors.

2. Apparatus for determining the radiation scattering coefficient S_θ within a fluid for the scattering angle θ comprising a fluid zone to contain a fluid; first radiation means including a first radiation detector and a first radiation source for emitting radiation through the fluid zone in a first straight-line path to the first radiation detector; second radiation means including a second radiation detector and a second radiation source for emitting radiation through the fluid zone in a second straight-line path to the second radiation detector, the second straight-line path intersecting the first straight-line path at an angle θ; excitation means connected to the first and second radiation sources; means for obtaining a first signal in accordance with the outputs A_{11} of the first detector due to radiation from the first radiation source; means for obtaining a second signal in accordance with the output A_{12} of the first detector due

to radiation from the second radiation source; means for obtaining a third signal in accordance with the output A_{21} from the second detector due to radiation from the first radiation source; means for obtaining a fourth signal in accordance with the output A_{22} from the second detector due to radiation from the second radiation source; and means for generating from the four signals a signal representing the scattering coefficient S_θ for the scattering angle θ.

3. Apparatus as claimed in claim 2, in which the generating means are arranged to combine together the first to fourth signals according to the equation

$$S_\Theta = \left[(A_{21}\ A_{12}) / (A_{11}\ A_{22})\right]^{1/2}$$

4. Apparatus as claimed in claim 3 in which the means for obtaining the first to fourth signals include a logarithmic circuit, and means for sequentially applying to said logarithmic circuit the outputs A_{11}, A_{21}, A_{22} and A_{12} to generate the logarithms thereof, and the generating means comprise means for combining the logarithms for generating

$$\log S_\Theta = 1/2 \left[(\log A_{21} + \log A_{12}) - (\log A_{11} + \log A_{22})\right]$$

and an anti-logarithmic circuit connected to the last named means for generating from $\log S_\theta$ the value of S_θ.

5. Apparatus as claimed in claim 4 in which the generating means further includes means for generating the time average of the S_θ signal.

6. Apparatus according to any one of claims 2 to 5 in which the excitation means are arranged to energise alternatively the first radiation source and the second radiation source.

7. Apparatus according to claim 6 further comprising first amplification means coupling the first radiation detector to the generating means and including first gain control means connected to the excitation means for decreasing the gain of the first amplification means when the first radiation source is energised, and second amplification means coupling the second radiation detector to the generating means and including second gain control means connected to the excitation means for decreasing the gain of the second amplification means when the second source is energised.

8. Apparatus for determining the scattering coefficient S_θ within a fluid for the scattering angle θ, substantially as hereinbefore described with reference to and as shown by the accompanying drawings.

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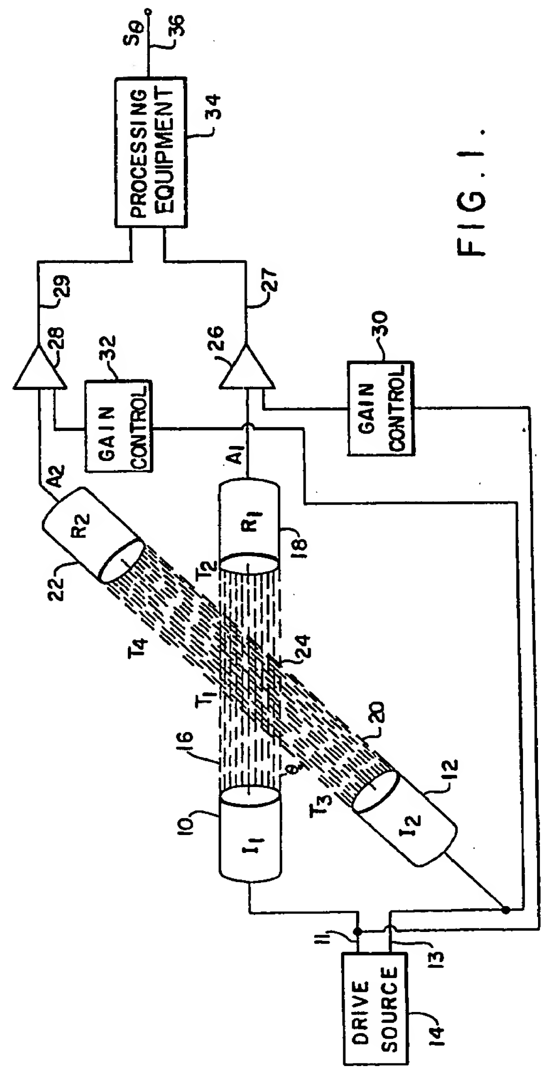
PROCESSING EQUIPMENT
34
Sθ
36
GAIN CONTROL
32
GAIN CONTROL
30
28
29
26
27
A2
A1
R2
R1
22
18
T2
T4
T1
24
20
16
θ
T3
10
I1
I2
12
11
13
DRIVE SOURCE
14

FIG. 1.

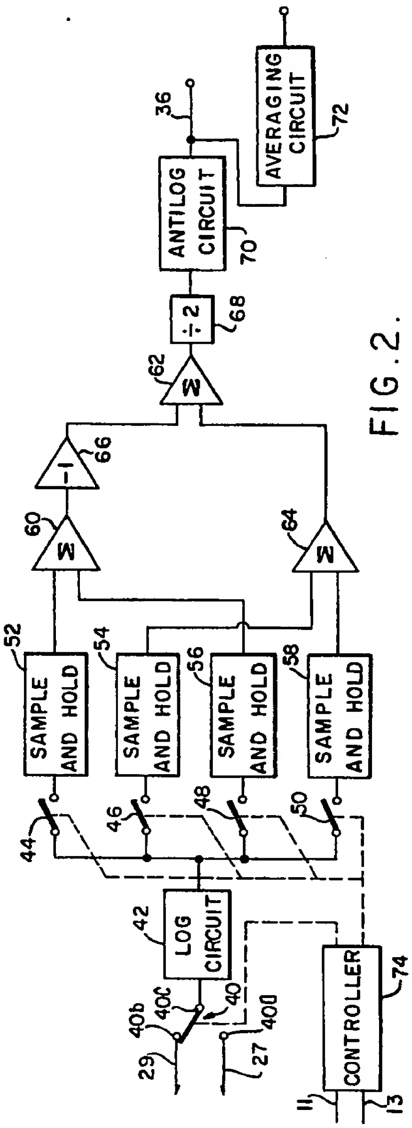
AVERAGING CIRCUIT
ANTILOG CIRCUIT
÷2
M
M
M
-1
SAMPLE AND HOLD
SAMPLE AND HOLD
SAMPLE AND HOLD
SAMPLE AND HOLD
LOG CIRCUIT
CONTROLLER

FIG. 2.